

X-621-68-265

PREPRINT

NASA TM XE 63343

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N 68-35822

(ACCESSION NUMBER)

(THRU)

20
(PAGES)

1
(CODE)

TMX-63343
(NASA CR OR TMX OR AD NUMBER)

13
(CATEGORY)

GPO PRICE \$

CSFTI PRICE(S) \$

Hard copy (HC)

Microfiche (MF)

ff 653 July 65

JULY 1968

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND



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IN THE F2 REGION

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ABSTRACT

Thomson scatter measurements at Arecibo (18.4°N, 67°W) indicate appreciable seasonal and day-to-day changes in the noontime F-region electron concentration, with a strong positive correlation between the height of the F-layer peak and the peak electron concentration. This correlation is theoretically reproduced by changing, first the neutral particle concentration and later the neutral wind velocity. The changes required in the neutral concentration are much too high to be explained on the basis of the available information on the atmospheric density from the satellite drag data. Horizontal winds directed polewards during winter and equatorialwards during summer, however, can reasonably explain the observed variations and are consistent in terms of the expected seasonal change in the position of the pressure (density) bulge with respect to Arecibo.

*NRC-NASA postdoctoral research associate.

ON THE SEASONAL AND DAY-TO-DAY VARIATIONS IN THE F2 REGION

INTRODUCTION

Wide day-to-day variability in the F-region electron concentration have recently been reported, from the Thomson Scatter measurements (Mahajan 1967), Mahajan et al., 1968), as well as from the Doppler fading of the radio transmissions from the geostationary satellites (Garriott et al., 1965; Klobucher and Whitney, 1966; Titleridge, 1966; Jones, 1968). These variations can either be interpreted in terms of changes in the neutral particle concentration or as changes in the electron drift velocity originating from neutral atmospheric winds (King and Kohl, 1965; Kohl and King, 1967; Rishbeth, 1967) and/or from electric fields (Chapman and Bartels, 1940; Kato, 1956; Maeda and Kato, 1966; Fejer, 1965). In this paper some further results on this variability are presented. Theoretical estimates of the changes in the neutral particle concentration and the drift velocity required to reproduce the observed variations are made and discussed in terms of our current knowledge on the neutral atmosphere and the atmospheric winds.

OBSERVATIONS AND DATA

The data used are essentially the same as employed by Mahajan et al. (1968) for the electron content studies over Arecibo (18.4°N, 67°W) and cover the period Sept. 1965 through Aug. 1966. These consist of the back scatter power measurements in the range 100 - 700 Km. Pulse transmissions of 500 μ s were used and sampled at intervals of 20 μ s with the digital autocorrelation technique developed by Perkins and Wand (1965). The electron concentration (N_h) for any height h is obtained from the measured power (P_h) as:

$$N_h = A \times P_h \times h^2 \left[1 + \left(\frac{T_e}{T_i} \right)_h \right] \quad (1)$$

where A is a constant involving primarily the parameters of the transmitting and receiving system, and $(T_e/T_i)_h$ is the electron to ion temperature ratio at the height h. The ratio T_e/T_i is deduced from the power spectra recorded simultaneously in the height range 250 - 550 Km. Outside this range T_e/T_i is obtained by linear interpolation by assuming this ratio to be unity at 100 and 1000 Km. As the constant A can not be obtained accurately, it is eliminated by forming a normalized electron concentration profile. The absolute scale of the profile is provided by scaling NmF2 from the simultaneously recorded C-3 ionograms.

Figure 1 is a plot of a number of electron density profiles on various days for about the same local time (11-13 hours). Significant change in the electron concentration from one observation to the next can be noted. This variability is examined in Figure 2 by plotting NmF2 against the observed peak height. We have tried to distinguish the various seasons by assigning different symbols for summer, winter and equinox. A strong overall positive correlation between hmF2 and NmF2 is evident, with some seasonal change in this correlation. The winter NmF2 and hmF2 values are consistently lower than the summer and equinox. In the sections to follow we shall try to reproduce the observed hmF2 - NmF2 correlation theoretically by changing the neutral concentration and then the wind velocity.

THEORY

We shall consider the F2 region to consist of oxygen ions within a neutral atmosphere of predominantly oxygen atoms. The oxygen ion concentration in the F2 region is controlled by photo ionization with production rate Q , charge transfer to molecules with loss rate $L[O^+]$ and transport of O^+ with a velocity v_{0+} . Assuming that the transport of ionization is only important parallel to the magnetic field, the steady state continuity equation has the form:

$$Q - L[O^+] - \sin I \frac{\partial}{\partial z} ([O^+] v_{0+}) = 0 \quad (2)$$

where I is the dip angle and z the variable altitude in the plane stratified ionosphere.

If one assumes that the plasma temperatures are constant with altitude, the motion equation has the form

$$\theta_{0+0} [O^+] [O] (v_{0+} - v_0) = - \sin I \left(kT \frac{\partial [O^+]}{\partial h} + m_0 g [O^+] \right) \quad (3)$$

where:

θ_{0+0} = drag coefficient of O^+ in O

v_0 = component of the wind velocity of O parallel to the magnetic field

T = $T_e + T_i$, the electron and ion temperature

m_0 = mass of O and

g = gravitational acceleration.

Substituting (3) in (2), one gets:

$$\sin^2 I \frac{\partial}{\partial z} \left[\frac{1}{\theta_{0+0} [O]} \left(kT \frac{\partial [O^+]}{\partial z} + m_0 g [O^+] \right) \right] + L [O^+] \equiv D \left([O^+] \right) =$$

(4)

$$\equiv \sin I \frac{\partial}{\partial z} \left(v_0 [O^+] \right) - Q$$

When $v_0 = 0$, Equation (4) can be solved analytically by its transformation to a Bessel differential equation (see e.g. Yonezawa, 1958; Geisler and Bowhill, 1965) if one assumes that the functions Q and L decrease exponentially as:

$$Q = Q_0 e^{-\frac{z - z_0}{q}} \quad (5)$$

$$L = L_0 e^{-\frac{z - z_0}{\ell}} \quad (6)$$

Here q is the scale height of O , the major ionizeable constituent and ℓ the scale height of N_2 or O_2 to which O^+ transfers its charge. This implies that the gas temperature is considered constant with altitude and that the attenuation of the ionizing solar UV radiation is neglected.

For the case $v_0 \neq 0$, Equation (4) can only be analytically solved if v_0 varies in a fashion such that:

$$v_0 = \frac{K}{[O]} ; K \text{ is a constant}$$

Under this condition a constant force $\propto \frac{A \theta_{0+0}}{\sin I}$, in addition to the gravitational force, would be applied to the ions. As this situation is not expected to exist,

Equation (4) has to be solved numerically. We have accomplished this by a perturbation method as summarized below.

The term $\sin I \frac{\partial}{\partial z} \left([O^+] v_0 \right)$ was considered as a perturbation in Eq (4), and it was applied in a successive iteration, such that in each iteration its effect was small. This method can be described in analytical form through a system of equations of the form as Equation (4) but with variable parameter ϵ_k ($0 \leq \epsilon_k \leq 1$)

$$D \left([O^+]_0 \right) = -Q$$

$$D \left([O^+]_1 \right) = -Q + \epsilon_1 \sin I \frac{\partial}{\partial z} \left([O^+]_0 v_0 \right)$$

$$D \left([O^+]_2 \right) = -Q + \epsilon_2 \sin I \frac{\partial}{\partial z} \left([O^+]_1 v_0 \right)$$

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$$D \left([O^+]_k \right) = -Q + \epsilon_k \sin I \frac{\partial}{\partial z} \left([O^+]_{k-1} v_0 \right)$$

The first equation in (7) for $\epsilon_0 = 0$ corresponds to the case $v_0 = 0$ and can be solved as previously described to give $[O^+]_0$. With this zero order solution,

the second equation in (7) is defined. This equation is then solved by expanding $\epsilon_1 \sin I \frac{\partial}{\partial z} ([O^+] v_0)$ in a series of exponential functions (two in our case) for each of which an analytical solution can be obtained. Depending on the magnitude of v_0 , the parameter ϵ_1 is such chosen that the difference to the previous solution $[O^+]_0$ is small compared to $[O^+]_0$. In this way the validity of the perturbation method is fulfilled. Through continuous application of this procedure and simultaneously increasing ϵ_k as

$$\epsilon_0 < \epsilon_1 < \epsilon_2 < \epsilon_3 \dots \leq 1,$$

this parameter approaches 1 as the Equation (7) approaches the Equation (4) to be solved. After this point, further iterations employ the correct form of Equation (4) and lead to a convergence of successive solutions $[O^+]_k$ which thus represents a solution of Equation (4).

RESULTS

We shall, for simplicity, assume a constant ionizing flux. While changes in the flux proportionally change NmF2, these do not affect the hmF2 for the equilibrium profiles (see Equation (4)). Since O and N₂ are the major neutral constituents controlling the F-region ionization, we shall examine the equilibrium profiles by changing the number density of these particles alone. As O₂ has been measured to be less than N₂ by a factor of 15 at 150 Km by Hall et al (1967), and since the reaction rate of O⁺ to O₂ is faster than O⁺ to N₂ only by a factor of 10, we shall not consider any effects of electron loss through O₂. Taking z_0 to be 200 Km, we use the following constants

1. Photon flux $= 3 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$
2. Ionization cross section of O $= 10^{-17} \text{ cm}^2$

3. Rate coefficient of O^+ to N_2 = $2 \times 10^{-12} \text{ s}^{-1}$
4. Drag coefficient of O^+ in O = $3 \times 10^{-32} \text{ gm cm}^{-3} \text{ s}^{-1}$
5. $\sin I$ (Arecibo, dip = 52°) = 0.8

An electron to ion temperature ratio of about 1.5 ($T_i = T_n = 900^\circ \text{ K}$, $T_e = 1500^\circ \text{ K}$) is assumed throughout the F-region. This sufficiently accounts for the thermal nonequality, because the F-region electron concentration is not very sensitive to T_e changes (Thomas, 1966), although wide day-to-day variability in the electron temperature can exist (see e.g., Mahajan 1967).

We have changed the O and N_2 concentrations in systematic steps. First the number density of O is varied for a fixed ratio of $[O]/[N_2]$ and later $[O]/[N_2]$ is varied for the previously used $[O]$. The results of these calculations are summarized in Figure 3 where a theoretical grid of $N_m F2 - h_m F2$ relationship has been generated for various $[O]$ and $\frac{[O]}{[N_2]}$ values. Figure 3 indicates that to reproduce the average variability observed in Figure 2, one would need more than a factor of 5 change in the O and N_2 concentration with a fixed $[O]/[N_2]$ ratio of about 2.0.

The effects of the wind on the equilibrium profiles are seen in Figure 4. Meridional winds with velocities of +15, 0, -15 and -100 m/sec parallel to the field lines have been used. The concentrations of O and N_2 employed are the experimentally measured values by Hall et al (1967) during March 1966 and are as follows:

$$[O] = 4.4 \times 10^9 \text{ cm}^{-3}$$

$$[N_2] = 2.3 \times 10^9 \text{ cm}^{-3}$$

As can be seen that the winds have a very strong effect on the electron concentration profiles. These effects are similar to the vertical drift effects reported

by Yonezawa (1958) and Rishbeth and Baron (1960). One can immediately see from Figure 4 that changes in wind velocity can reasonably account for the average variability observed in the electron concentration. It is also clear that one would need equatorialwards winds (positive velocities) during summer and polewards winds (negative velocities) during winter at Arecibo to explain the observed seasonal changes in NmF2 and hmF2.

Another result evident from Figure 4 is that the effect of poleward winds on the electron concentration profiles is relatively smaller than that of the equatorialward winds. This is expected to be so since high poleward winds bring the F-layer peak close to the chemical equilibrium region.

DISCUSSION

It is clear from Figure 3 that to explain the observed winter to summer change in NmF2 and hmF2, one would need a factor of 5 change in the O and N₂ concentrations and thus in the atmospheric density. As a matter of fact no significant seasonal changes in the atmospheric density from the satellite drag data have been reported (see Priester et al, 1967 for a review on satellite drag results). Also the ion temperature measurements at 250 km ($T_i = T_n$ at 250 km, Nisbet 1967) during these observations indicate neither any appreciable seasonal change in T_i nor any systematic dependence of hmF2 (and/or NmF2) on T_i . Thus it is difficult to invoke changes in the neutral concentration as the cause of the F-region electron concentration variations.

As we have seen, the atmospheric winds can reasonably account for the observed variability. Geisler (1966) has calculated the model wind systems for the

F-region for mid latitude stations. He has found poleward winds during the daytime with velocities higher in winter than summer. As the diurnal bulge in atmospheric density (and thus in pressure) migrates in latitude in phase with the subsolar point (Jacchia, 1965; Jacchia and Slowey, 1968), the bulge is expected to be north of Arecibo during most of the summer. This would give rise to equatorward winds — a conclusion in conformity with our results in Figure 4. Due to the location of the diurnal bulge to the south of Arecibo in winter and equinox, one would then expect poleward winds, which is again consistent with our results. The cause of the changes in the wind speed during the same season is, however, not known. It does seem evident that small changes in the wind velocity during summer and equinox (positive velocities or low negative velocities) would result in relatively greater change in the electron concentrations than during winter. The wide day-to-day variability (about a factor of three) in the electron content data of Klobuchar and Whitney (1966) during the summer of 1965 lends support to this prediction.

We have implicitly neglected any effects of the electric fields in our calculations, since we have assumed the ionization to move along field lines. Electric fields, if present, would have a similar effect on the ionization transport as the meridional winds. However, in the absence of any measurements, it is rather difficult to test their effects on the F2 region.

ACKNOWLEDGEMENTS

We gratefully acknowledge valuable comments by Mr. H. A. Taylor, Jr.

This work was performed while both of us were NRC-NASA postdoctoral resident research associates. The data used in this study was collected by the

resident members of the Arecibo Ionospheric Group under a regular observational program. The Arecibo Ionospheric Observatory is operated by Cornell University with the support of the Advanced Research Projects Agency under a research contract with the Air Force Office of Scientific Research.

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FIGURE CAPTIONS

- Figure 1. Electron concentration profiles from Thomson scatter measurements at Arecibo, Puerto Rico. All profiles correspond to about the same local time. The day-to-day and seasonal changes in the concentration can be noted.
- Figure 2. A plot of $N_m F_2$ against $h_m F_2$ for observations on various days during the period Sept. 1965 to Aug. 1966. Times between 11-13 hours have been used.
- Figure 3. Theoretical relationship between $h_m F_2$ and $N_m F_2$ for various values of $[O]$ and $[O]/[N_2]$. The values of the other parameters used in the continuity equation are given in the text.
- Figure 4. Theoretical electron density profiles showing the wind effects. The O and N_2 concentrations used have been taken from measurements by Hall et al (1967) and very nearly correspond to the same solar activity conditions as our N-h data. The velocities are the component along the field lines. The horizontal velocities will be twice the numbers $\left(\text{i.e. } \frac{1}{\sin I \cos I} \right)$ shown in the diagram.

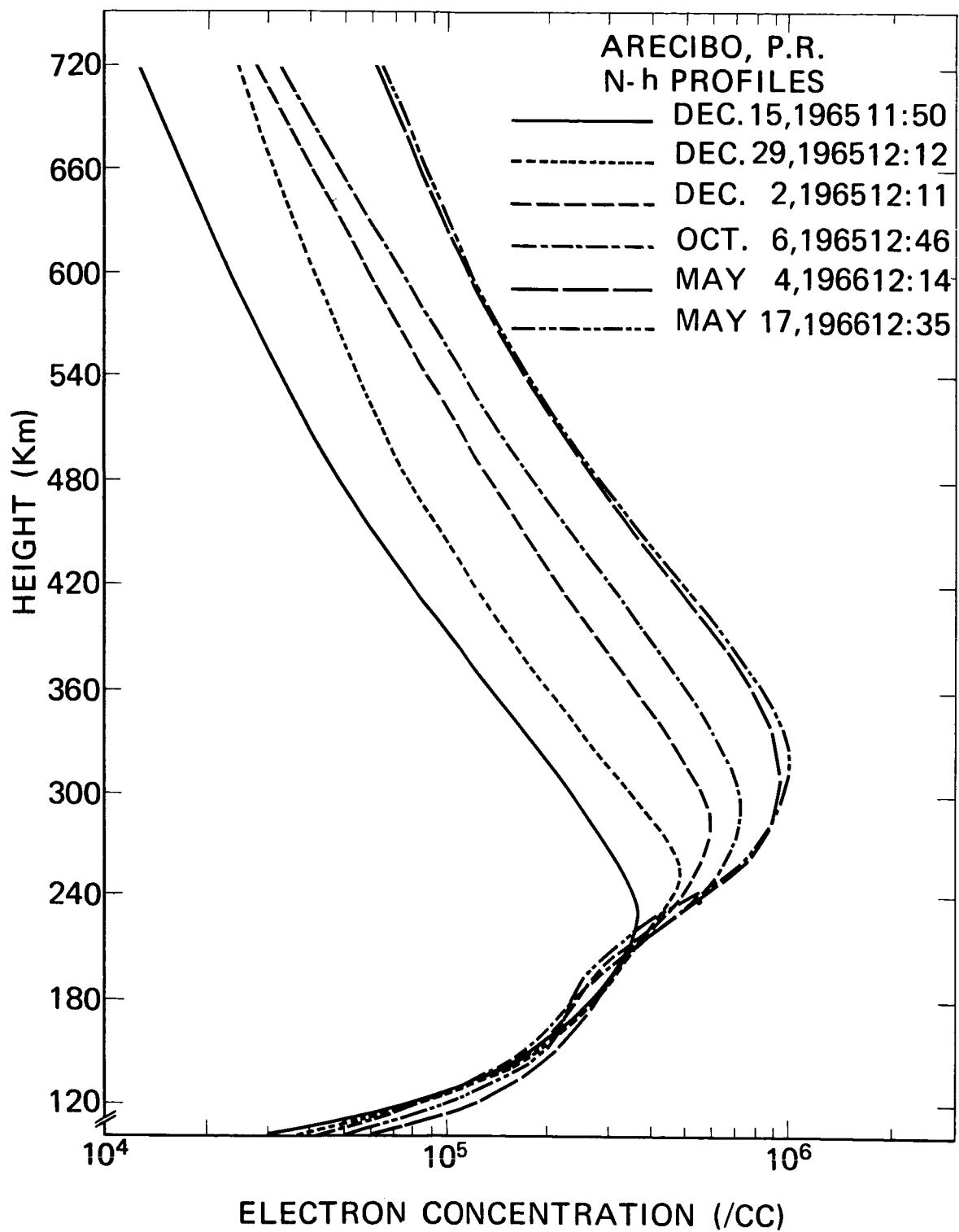


Figure 1. Electron concentration profiles from Thomson scatter measurements at Arecibo, Puerto Rico. All profiles correspond to about the same local time. The day-to-day and seasonal changes in the concentration can be noted.

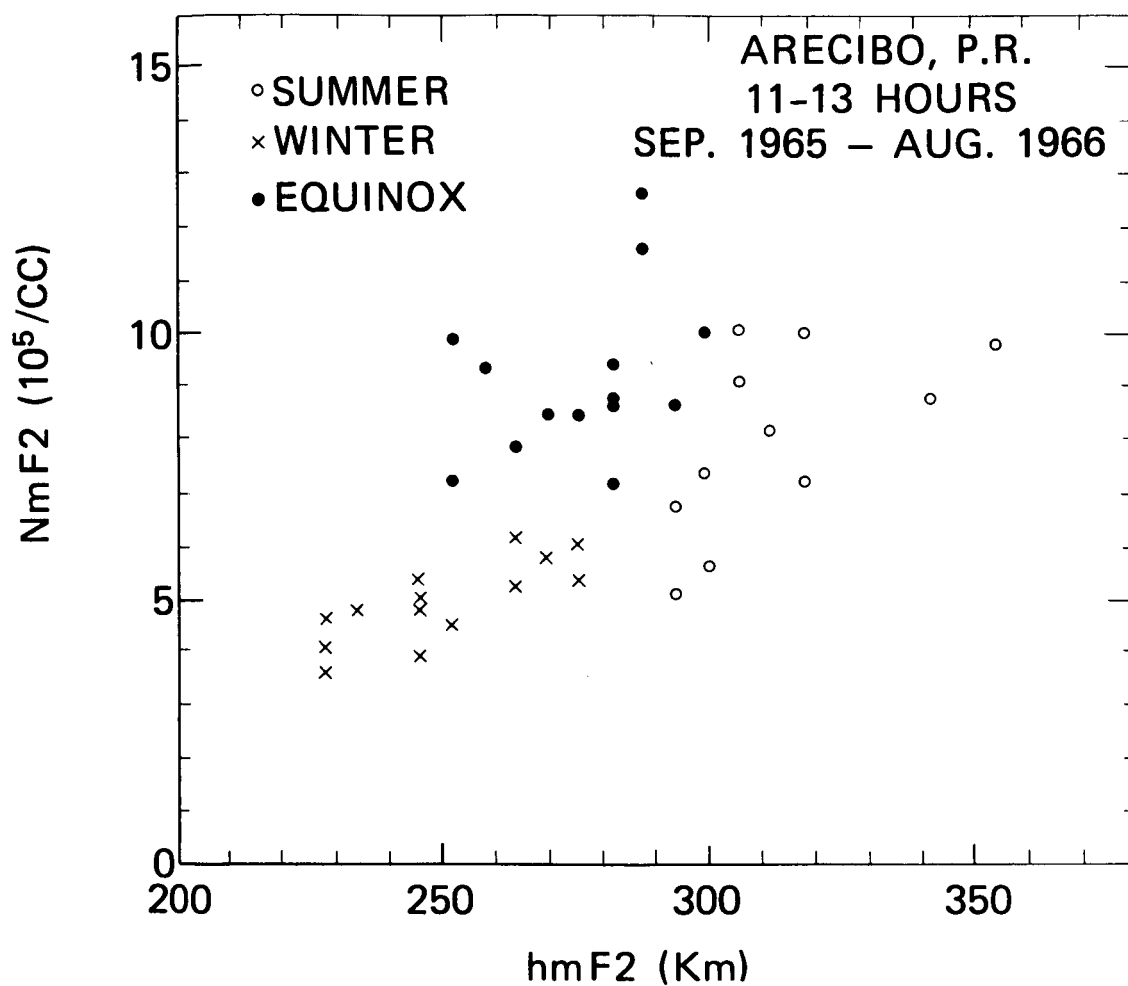


Figure 2. A plot of NmF2 against hmF2 for observations on various days during the period Sept. 1965 to Aug. 1966. Times between 11-13 hours have been used.

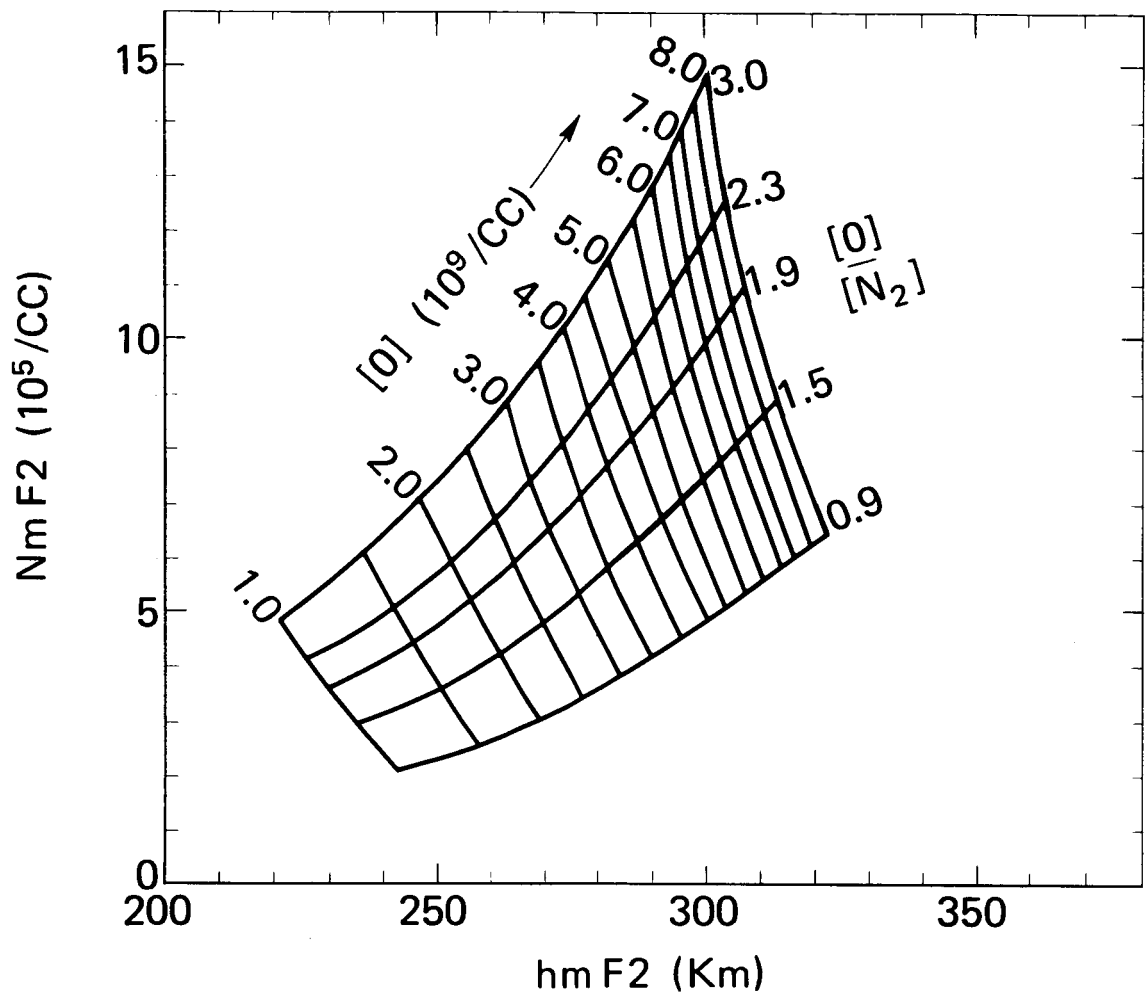
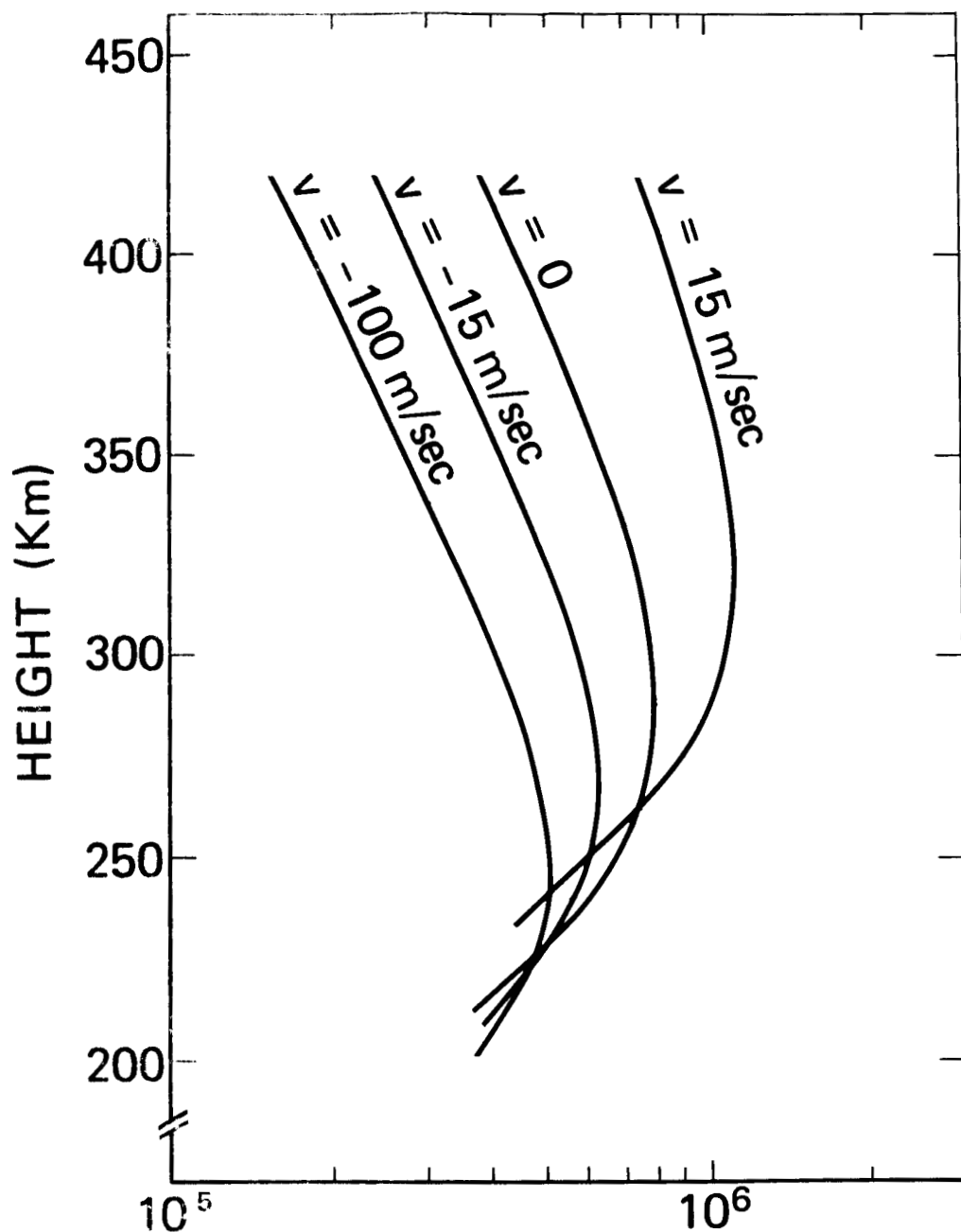


Figure 3. Theoretical relationship between $hmF2$ and $NmF2$ for various values of $[O]$ and $[O]/[N_2]$. The values of the other parameters used in the continuity equation are given in the text.



ELECTRON CONCENTRATION (/CC)

Figure 4. Theoretical electron density profiles showing the wind effects. The O and N₂ concentrations used have been taken from measurements by Hall et al (1967) and very nearly correspond to the same solar activity conditions as our N-h data. The velocities are the component along the field lines. The horizontal velocities will be twice the numbers $\left(\text{i.e. } \frac{1}{\sin I \cos I} \right)$ shown in the diagram.